Real-Time Driving Simulation of Magneto-Rheological Active Damper Stryker Suspension

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ABSTRACT

Real-time driving simulations are an important tool for verifying vehicle and vehicle component designs with a driver in the loop. They not only provide a cost effective solution but also an ability to verify designs in a safe and controlled operating environment. A real-time driving experiment has been developed for Stryker to compare the ride and handling performance of a baseline passive suspension to that of a Magneto-Rheological (MR) semi-active damper suspension. The Tank Automotive Research Development and Engineering Center (TARDEC) has integrated this new suspension into a real time vehicle dynamics model of the Stryker using the MR suspension model developed by the Original Equipment Manufacturer (OEM). Using this real-time model and the TARDEC Ride Motion Simulator (RMS), TARDEC associates, along with associates from the Stryker Program Management office and the suspension OEM were able to drive and compare the passive and MR Stryker in a virtual environment. This paper describes the simulation model, motion simulator integration, operating scenarios, terrain modeling, model validation, and subjective as well as objective results from this study.

1. INTRODUCTION

The TARDEC team has been working with the suspension OEM to assess the possible improvement and feasibility of integrating a Magneto-Rheological (MR) semi-active damper suspension into the Stryker Family of Vehicles (FOV). A magneto-rheological damper is filled with magneto-rheological fluid, which is controlled by a magnetic field, usually using an electromagnet [1]. This allows the damping characteristics of the shock absorber to be continuously controlled by varying the power of the electromagnet. Due to its flexibility to adapt to a range of damping needs using custom control systems, MR dampers have been studied by many manufacturers to develop optimal ride solutions. Many studies in the past demonstrated its usefulness either by solely conducting modeling and simulation, or by full vehicle testing [2]. While a pure M&S approach is efficient, it lacks subjective feel. On the other hand, though full vehicle testing presents higher confidence since it tests the full system and physical hardware, it is prohibitively expensive in many cases. Real-time driving simulation presents a reasonable compromise between M&S and testing where a driving simulator simulates a vehicle dynamics model while providing the desired subjective feedback to the driver.

To help demonstrate the feel of the baseline system and compare it to the MR system, a driving simulation model was developed. The simulation was conducted on TARDEC's Ride Motion Simulator (RMS), a 6-Degree of Freedom (DOF) hexapod simulator. A "black-box" Simulink® model for the MR damper, as provided by the OEM, was integrated into the Stryker passive dynamics model. The "black box" model contained the control logic for the MR damper system but the code was not able to be viewed or edited due to the proprietary nature of the system.

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2. DRIVING SIMULATOR ENVIRONMENT

The hydraulically driven Ride Motion Simulator (RMS) consisted of LCD screens for out the window view of environment, a speaker system for vehicle sounds, a steering wheel, and pedals. The RMS is a 40 Hz single occupant simulator capable of producing linear accelerations of ± 2g's (lateral, longitudinal, vertical) and angular accelerations of $\pm 1150 \text{deg}/_{\text{sec}}^2$ (roll, pitch, yaw). It can be used to reproduce the ride of both wheeled and tracked military ground vehicles.

Figure 1: Ride Motion Simulator (RMS)

One of the major challenges faced by simulation engineers is the limitation of 6-DOF driving simulators to recreate the sustained lateral or longitudinal accelerations found in real world driving due to the limited motion envelope. The RMS has a linear range of ± 20 in (508 mm) and an angular range of ± 20deg. To make up for the limited motion envelope, simulation engineers utilize washout/tilt-coordination filtering [3] which augments lateral and longitudinal accelerations with roll and pitch displacements. For instance, when the driver makes a right turn the simulator will accelerate left until it reaches a limit and will then roll left.

From a programmatic perspective, the driving simulator has the following cueing systems: audio, out the window graphics, driving control interface, and motion. These systems are encapsulated as modules and integrated with the vehicle dynamics to form the driving simulator. In this case the simulation tool would resolve the calculation order for the entire simulation. For example, vehicle controls would be calculated first, followed by the vehicle dynamics and then the various cueing systems.

In order to drive the simulator, real-time dynamics models of the two Stryker variants were developed using a commercial software, SimCreator®. The simulated MR damper control component, developed by the suspension OEM, used the same control logic as the actual vehicle system.

3. STRYKER MODEL

Many commercial real-time vehicle dynamics software packages exist in the market that could be used to support this experiment. The TARDEC RMS is currently configured to use SimCreator® software. SimCreator®'s multibody dynamics [4] component library is based on the Composite Rigid Body Methods

(CRBM) developed by Walker and Orin and authored by Romano [5]. CRBM method is used for the open kinematics chains. To handle closed kinematics chains, constraint equations with corresponding Lagrange multipliers are introduced and are used to augment the dynamics equations with constraint equations. For each constraint equation, a second-order dynamic system is also introduced that minimizes position and velocity errors during the simulation.

The Stryker vehicle model consists of four independent axles: two in the front and two in the rear (Figure 2). All axles are driven and consist of Macpherson Strut suspensions with the front two axles as steering axles. All suspension kinematics are represented parametrically using ride and camber curves. Suspension stiffness and damping were represented at the wheel using representative motion ratios. The vehicle model was tuned to match corner weights and weight distribution, with the representative inertial properties. A non-dimensionalized magic formula approach [6] was used for the tire modeling.


**Figure 2: Stryker Vehicle Configuration**

3.1 MODEL VALIDATION

Using a driver-in-the-loop, the Stryker vehicle model was validated for:
1) Maximum lateral acceleration on a skidpad,
2) NATO lane change [7], and
3) Ride on a Belgian Block terrain.
The maximum lateral acceleration was achieved with a steady state cornering procedure by driving the vehicle model at a constant speed of 40 mph (64.3 kph) and slowly increasing the steering angle until it began to slide. The vehicle model achieved the maximum lateral acceleration of 0.43G which seemed reasonable based on the historical test data. A NATO lane change maneuver was simulated at 40 mph (64.3 kph) and compared against test for the roll rate as shown in Figure 3. Both test and simulation indicated the maximum roll rate between 10-12 deg/sec. Figure 4 shows the comparison across a straight section of the Belgian Block course for the vertical acceleration near the driver's seat location. The Belgian Block terrain was developed using Non Uniform Rational B-Spline (NURBS), discussed next in more detail. Though the terrain and vehicle did not precisely reproduce the ride seen from the field data, the difference between the passive and MR variants was deemed close enough to be a useful assessment tool.
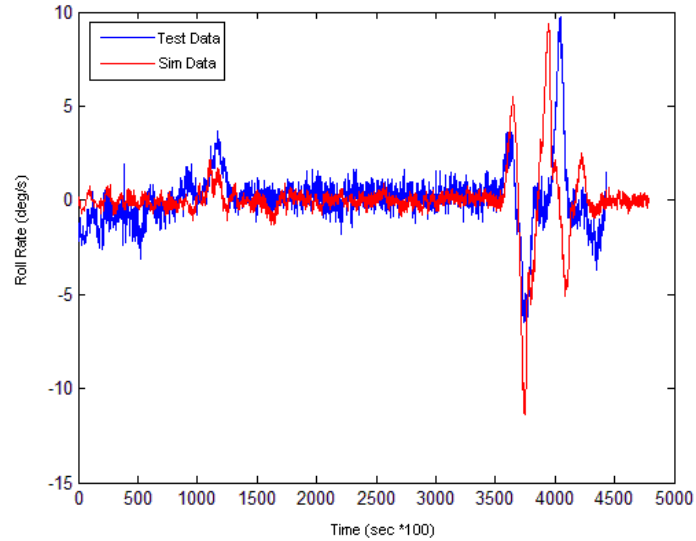
Figure 3: MR Stryker NATO Lane Change Field Test vs. Simulated Roll Rate (40 mph / 64.3 kph)
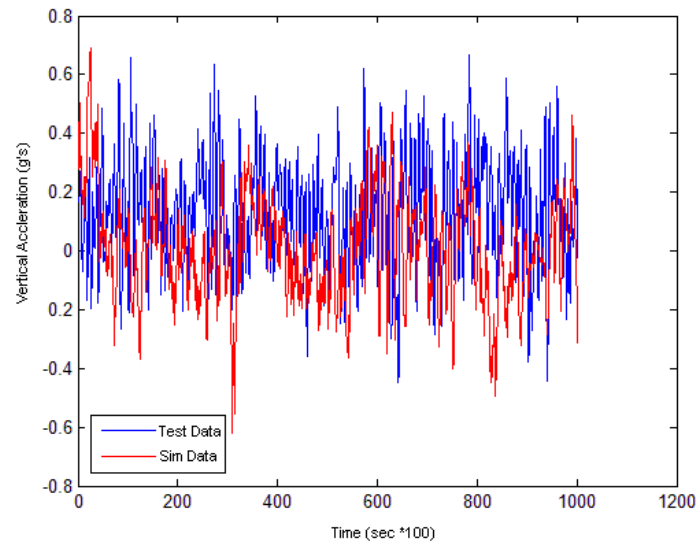

Figure 4: Sample Vertical Acceleration Data om the Belgian Block Course

4. TERRAIN MODELING FOR RIDE COURSES

Also integrated into the simulation was a virtual terrain for participants to drive on in real time. The participants drove the vehicle on two different simulated terrains. The first one was a simple linear bump course consisting of a line of two sizes of triangular bumps. The first were 0.26 m high, 6 m long (in direction of travel) and 10 m wide. The second were 0.13 m high, 6 m long, and 10 m wide. The bump course was meant to give the occupant a simple input to compare the suspensions while they got used to how the simulator behaved during driving. The second course was a simulated version of The U.S. Army's Aberdeen Proving Grounds Munson Test Area. Within Munson, occupants drove over a portion of the Munson Gravel course and all of the Belgian Block course. Overview images of the two courses are shown in Figures 5 and 6.

Figure 5: Simulated Munson Test Area
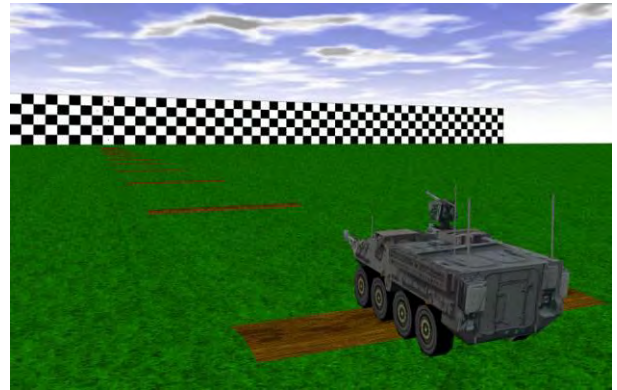
Figure 6: Linear Bump Course

The Munson test area was determined to be a suitable terrain to test the ride of the MR suspension. However, in order to develop a terrain that will allow the simulation to run in real-time as well as be visually and physically accurate, the terrain database needed to be simplified. For simplification, the terrain database was separated into two files. One file contained the visual database which consisted of the polygonal representation of the terrain and the overlay textures. The other contained higher resolution data of the courses being driven.

Initially, the modeled test courses did not contain enough resolution to produce a vehicle response that would adequately highlight the difference between the passive suspension and the semi-active MR suspension. For graphics to run smoothly in real time the complex road details were replaced with largely flat polygons which describe the general shape and large bumps on the road. While this may be suitable for some experiments, it is not acceptable for a suspension evaluation. Preliminary drives on the terrain produced rigid body mode frequency response below 2Hz. To obtain higher frequency road roughness a technique known as texture bump mapping was applied to the roads [8]. These bump map textures were applied to the second terrain file which consisted of the same polygonal representation but included the higher frequency bump maps. The bump map for the Belgian Block course was a vertical height field which used the visual texture for the spacing of the bricks and was scaled vertically to produce the desired suspension mode frequency band (around 10-15 Hz). However, the energy content of the suspension modes in the simulation did not reach the level seen in the field test data but it was deemed close enough for a subjective comparison of the suspensions. For the Munson Gravel course a bump mapping technique utilizing Non-Uniform Rational B-Spline (NURBS) was used to produce road roughness representative of a gravel road. The NURBS were generated using the root mean square for the gravel road.

5. RIDE DEMONSTRATION RESULTS

A team of engineers from TARDEC, TACOM and the OEM took the opportunity to drive a simulated passive and MR damped Stryker. Though this wasn't a formal test to gather data, some ride data was collected by measuring command accelerations to the simulator. Also, participants gave their subjective opinions of the ride of the Stryker with and without the MR suspension as a blind evaluation.

On the linear bump course all participants could tell which vehicle was the passive suspension or the MR suspension and unanimously preferred the MR damper. On the Belgian Block course, it was suggested to drivers to maintain a vehicle speed of 25 mph (40.2 kph) to best feel the difference in the two suspensions. However, many drivers did not maintain 25 mph (40.2 kph) due to simulator discomfort which resulted in many

of the drivers not being able to feel the difference between the two variants. Also, it was determined some participants couldn't get used to the washout algorithms that are used to move the simulator. When the simulator has to produce a sustained linear acceleration but hits the end of its travel, the simulator tilts to make up for the lack of linear space. The washout algorithms may have caused some participants to believe the vehicle was pitching/rolling more than it actually was. However, the objective analysis of accelerations during those maneuvers showed demonstrable benefit of the MR damper over the passive one. As shown in Figures 7 and 8, the MR suspension significantly reduced the magnitude vertical accelerations and lowered the absorbed power [9] of the ride.
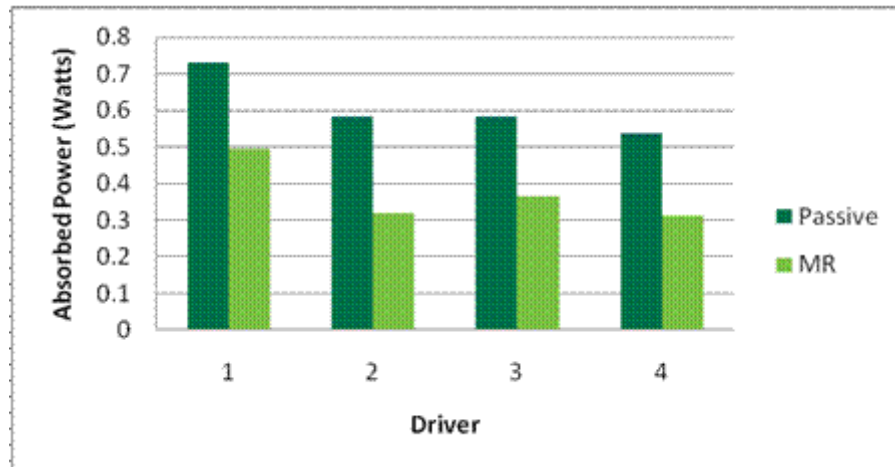
Figure 7: Sample Absorbed Power Comparison
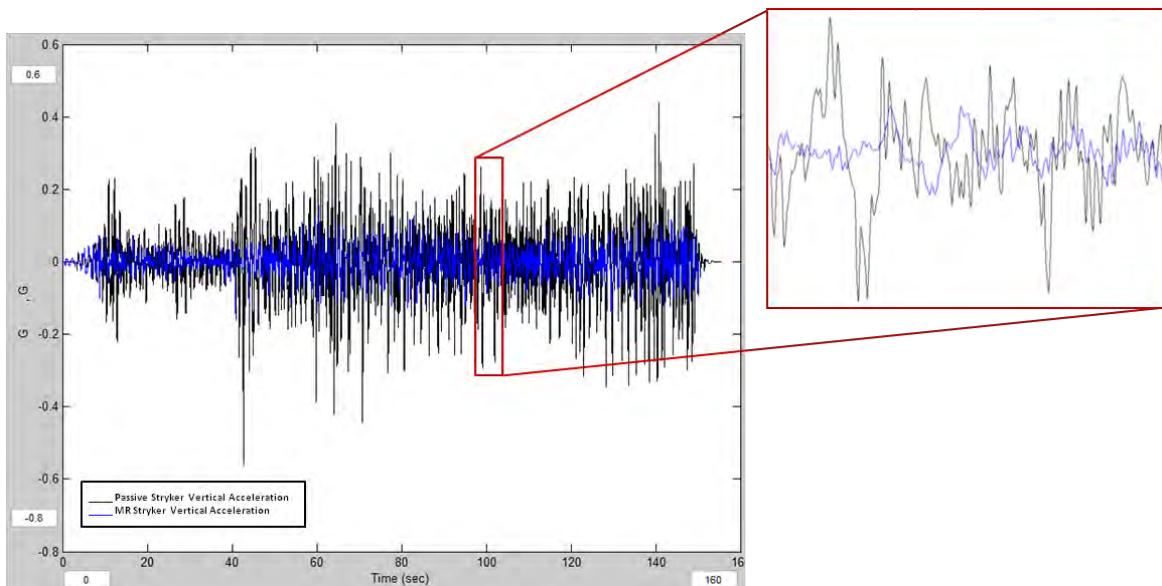
Figure 8: Effect of MR damper on the Vertical Acceleration

SUMMARY/CONCLUSIONS

By allowing engineers to ride the different Stryker variants, they were able to feel for themselves the difference the MR suspension makes on the ride of the vehicle. Based on the data and the responses from participants, it is apparent the MR system improves the ride of the vehicle. Improved ride will certainly help fatigue and comfort of Soldiers, but how it translates to improved combat effectiveness was not studied. A possible next step for this program would be to study Soldiers driving both vehicles in a simulated theater environment with a mission objective and enemy engagements. This would not only test how Soldiers feel about the smoother ride of the vehicle from a comfort perspective but will also allow engineers to study how the suspension effects vehicle use, target recognition and engagement.

REFERENCES

1. Lord Corporation, www.mrfluids.com.
2. "Army Looks at Improving Vehicles' Performance With MR Fluid Technology From Lord Corporation," www.PHYSorg.com , 20 Jul 2004.
3. Romano, R. "Non-Linear Optimal Tilt Coordination For Washout Algorithms" *AIAA Modeling and Simulation Technologies Conference*, August 2003.
4. *SimCreator Training Manual*, Real-time Technologies.
5. Romano, R., "Realtime Driving Simulation using Modular Modeling Methodology," *SAE Paper* 2000-01-1297, April 2000.
6. Miliken W., and Miliken D.*, Race Car Vehicle Dynamics*, SAE International, p473-487, 1995.
7. Allied Vehicle Testing Publication (AVTP) 03-160, 1991.
8. Morrison, M. Et al. "High-Frequency Terrain Content and Surface Interactions for Off-Road Simulations," *SAE Paper* 2004-01-2641, April 2004.
9. Lee, R. A., Pradko, F., "Analytical Analysis of Human Vibration," SAE Technical Paper 680091, 1968, doi: 10.4271/680091.

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